Complete 2 of 2 (1-21).

With the Authors Compts

Recd and acknowledged
april 25. 1878

THE CONDITIONS

J. F. Campbell

EXISTING DURING

THE GLACIAL PERIOD;

WITH AN ACCOUNT OF

THE GLACIAL DEPOSITS

IN THE VALLEY BETWEEN

TRANMERE AND OXTON,

BY

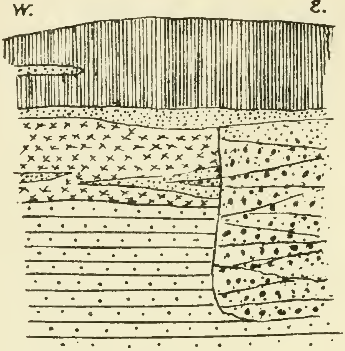
CHARLES RICKETTS, M.D., F.G.S.

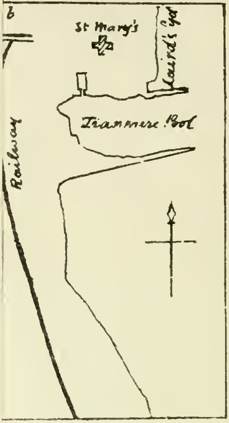
(Reprinted from the Proceedings of the Liverpool Geological Society, 1876–77.)

LIVERPOOL:
COURIER PRINTING WORKS, VICTORIA STREET.

1878.

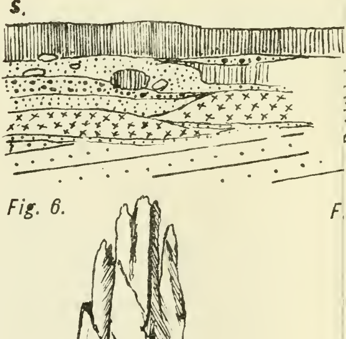
Fig. 1.

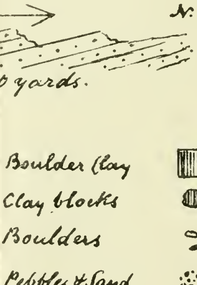




Mile.

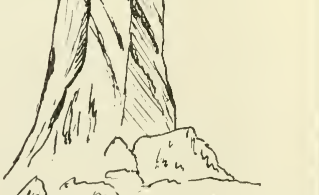
Fig. 2.





0 yards.

Fig. 6.



'Cathedral Rock.' Colorado.
height 250 feet.

F

Boulder Clay	▥
Clay blocks	▥
Boulders	○ ●
Pebbles & Sand	⁘
Sand	⁖
Moraine Sand	××××
Trias	☰

Sections 1 to 4 = 1/10 in. to foot

Icemarks →; locality shown by the angle

19.

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THE CONDITIONS EXISTING DURING THE GLACIAL PERIOD; WITH AN ACCOUNT OF THE GLACIAL DEPOSITS IN THE VALLEY BETWEEN TRANMERE AND OXTON.

By Charles Ricketts, M.D., F.G.S.

(Read before the Liverpool Geological Society, January 9th, 1877.)

The examination only of the beds, or of the materials which constitute the major portion of any geological formation, will rarely enable us satisfactorily to determine the circumstances under which deposits have been laid down, the manner in which they have originated, or from what sources derived. Due consideration must certainly be given to the evidences afforded by those sediments which have a similar character over large areas; but it is necessary that an equal regard be given to the deposits which in different localities are situated at and form their base; the contour of the underlying rocks must also be taken into consideration before a satisfactory elucidation of the problem can be discovered.

When attention had been so far directed to the Boulder-clay formation that the erratic pebbles, so many of which have all irregularities ground away and their surfaces rendered smooth, often grooved and striated, had been in some instances traced to certain known localities, it was at first considered that not only had these ice-marked boulders been floated on floes or bergs, which on melting dropped them in the localities where they are found, but also that the whole of the clay in which they are embedded had been conveyed in a similar manner. This idea was entirely set aside when, in many places in the valley of the Mersey, on the removal of this clay, the underlying rock-surfaces were, over large areas, discovered to be smoothed and striated, the grooves being so regular in direction that, by no possibility, could the opinion be maintained that these striations were caused by the grounding of icebergs; but, as they correspond entirely with markings on rock-surfaces formed by glaciers now existing, their origin can only be attributed to a similar action; and there is no other known agency by which they could be produced. The inference almost necessarily followed that, as streams issuing from beneath glaciers are always highly surcharged with mud, the clay itself deposited in this glacial sea had resulted from the degradation of rocks in the district, as a consequence of the eroding action of such glaciers in their passage down the valleys, which terminated in what is now the Bay of Liverpool.

Of the possibility that such was the method of the production of this clay, convincing proof has been given by the eminent Arctic observer, Dr. Robert Brown, F.R.G.S. He shewed that in Greenland a clay, so similar that no appreciable difference can be found between it and the brick-clay or fossiliferous Boulder-clay, is formed as a deposit from the waters which issue from beneath the Glaciers as Sub-glacial rivers, thickly loaded with the mud resulting from the grinding of the Glaciers on the infrajacent rocks. These Sub-glacial rivers pour out from beneath the Glacier, whether it lies at the sea or in a valley; their stream flows in a torrent the whole year round, and, reaching the sea, discolours the water for miles, and finally deposits on the bottom a thick coating of impalpable powder.*

Much attention has been directed to the consideration of the causes which induced a climate of such intensity as to cover with a mantle of perennial snow not merely Britain, but also, and at the same time, immense districts now amongst the most fertile in the Northern Hemisphere. Some, without, as I think, any sufficient evidence, imagine that the area surrounding the South Pole is entirely covered with a thick capping of ice; that the whole of this supposed continent, about 2,800 miles in diameter, is covered with one continuous sheet of ice, gradually thickening from its edge to its centre; and it is presumed that twelve miles would be a moderate amount to ascribe to the thickness of this cap at the Pole. They overlook the effects of intense cold in precipitating moisture contained in the atmosphere. With a winter of such severity as occurs within the Antarctic Circle, the whole of the water would be removed before the winds could pass over a radius of 1,400 miles. Certainly there would be no snow covering the ground within many degrees of the Pole which would not be removed by the heat of the sun during the long day of summer.† The existence of such a monstrous ice-cap at the South Pole having been taken for granted, it has been imagined that, during the Glacial Period, the whole of the waters of the Arctic Ocean formed one mass of ice, with snow thickly piled upon it, and on the larger portion of the land situated in the Northern Hemisphere. Such an accumulation of snow as is here supposed is not only at variance with physical laws at present existing, but, if it possessed the motion which Glaciers have, would have entirely swept away the remains of the Mammoth, Woolly-haired Rhinoceros, and other animals so commonly found in Siberia and the northern parts of America.

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* "Physics of Arctic Ice," by Robert Brown, Ph. D., F.R.G.S.—*Quart. Journ. Geol. Soc.*, vol. xxvi, p. 681.

† Captain Nares reports that, in the Arctic Expedition, on June 13th and 21st, a thermometer, with a blackened bulb *in vacuo*, exposed to the sun's rays, registered + 128° and + 129° Fahr. respectively; the temperature of the earth's surface at the time being + 27°, and of the air + 34°.

Appearances have been observed in Central America which have been *supposed* to indicate the former existence of Glaciers within 13° of the Equator, and it has been considered that these "covered all the higher ranges, and descended in great Glaciers to at least as low as the line of country now standing at two thousand feet above the sea, and probably much lower."* Such a condition has been referred to what is known as the Glacial Period. Mr. Belt's examination of the deposits on which he founds this opinion was too cursory, and the inferences are so entirely opposed to the physical conditions now existing there, for them to be readily accepted without further examination. The determination must be left to the investigation of future observers.

Such an hypothesis is incompatible with observations made by the United States Geological Survey of Colorado.† In the district of the Upper Arkansas, about the latitude of 39° N., where "the general elevation of the Sawatch Range for 60 or 80 miles is 13,000 or 14,000 feet above the sea," and that of the bed of the River Arkansas from about 7,500 to 9,800 feet, there is abundant evidence of Glacier erosion, and "the sides of the mountains are worn smoothly and exhibit signs of Glacial action to the height of at least 1,500 feet above the valley," an immense amount of moraine *débris* resulting from it remaining unremoved; whilst about 80 miles to the east, upon the same parallel of latitude, near Colorado City, situated at a height of 6,000 feet in the river-bed, and at about 7,500 feet at the water-divide, so far from there being this evidence of the previous existence of Glaciers, there are most remarkable examples of *subaërial* erosion—massive Triassic (?) Sandstones, fifty feet and upwards in height, weathered into the most fantastic shapes, some of which are isolated monoliths; amongst them is a magnificent natural obelisk, 250 feet high, called the "Cathedral Rock," situated in the "Garden of the Gods," Colorado; (Fig. 6.) whilst in rocks of later formation are numerous peculiar columns in "Monument Park." (Fig. 7.) Any of these would have been broken away by the pressure of an accumulation of snow persisting during comparatively a few years.

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* "The Naturalist in Nicaragua," by Thomas Belt, F.G.S.; p. 262.

† "Report of the United States Geological and Geographical Survey of Colorado, &c., for 1874."

If, by any possibility, such a climate could have existed in Equatorial regions, there must necessarily at the same time have been a period of most intense cold during winter in higher latitudes; but, with such conditions, the atmosphere could not be supplied with watery vapour, as it is now, more or less directly from Equatorial waters; so that there would be but little contained in it to be precipitated in more northern climes, and therefore Glaciers could not exist there. It would be as impossible for there to have been the system of Glaciers which *are known* to have existed in North America and in

Europe, as it would be for a steam engine to be set in motion without a fire underneath the boiler. "The lesseinng of the sun's heat would infallibly diminish the quantity of aqueous vapour, and thus cut off the Glaciers at their source." *

Respecting the conditions which prevailed in our own country, it has been assumed that "the Irish Sea was filled with an immense Glacier moving southwards, having a thickness of at least 2,000 feet; that it butted against the Welsh mountains, and, dividing, one part pushed *up* the valleys of the Mersey and Dee, and through what has been called the Straits of Malvern." †

Prof. Ramsay, in a paper read before the Geological Society last year, ‡ without recognising a polar ice-cap, attributes the glaciation of Anglesey to a vast mass of ice moving southwards from Cumberland, reinforced by ice-streams that came from the Mountains of Carrick, in the south of Scotland, and perhaps even from the basin of the Clyde. He considers that this enormous Glacier overspread the region now occupied by the low ground of Anglesey, and went to some unknown distance beyond. There are exposures in Anglesey which afford evidence that the *latest* glaciation of the island did not result from such a system of Glaciers as has been supposed. Thus in the circumscribed area of Serpentine, lying a little south of Valley Station, on the Holyhead Railway, there is exposed a smooth and striated surface covered with a moraine *débris*, so completely derived from the immediate locality that it *entirely* consists of angular fragments of the Serpentine itself; and at Llanerchymedd, on the Anglesey Central Railway, the striæ on a boss of rock situated close to the station have a direction *towards* S. 10° W., varying, as they curve round it, to S. 20° W. Professor Ramsay remarks that the Glacial striæ of the Island of Anglesey run generally in a direction from 30° to 40° west of south, and that "these striations point directly to the mountains of Cumberland;" but this is also very nearly the same direction as that of the Pre-Carboniferous valley, in which, on its subsidence, the Carboniferous Limestone and Millstone Grit were deposited; so that the Glaciers flowed in channels, which had been marked out by the comparative hardness of different rocks that have existed from Palæozoic times.

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* "The Forms of Water," by John Tyndall, LL.D., F.R.S., p. 21.

† "The Climate of the Glacial Period," by Thomas Belt, F.G.S. *Quarterly Journal of Science*, Oct., 1874.

‡ "How Anglesey Became an Island," by Professor A. C. Ramsay, F.R.S., *Quart. Journ. Geol. Soc.*, vol. xxxii, p. 116.

Observations made in the valley of the Mersey are altogether at variance with the idea of such an enormous ice-sheet as has been supposed. There are abundant evidences that it and its tributaries were filled with Glaciers, not progressing from an immense accumulation in the north, but formed by the snowfall in the respective valleys, being of such an extent only as might reasonably be considered due to the amount of deposition on their water-slopes. In numerous localities around Liverpool the Triassic rocks, where protected from the action of the weather by the overlying Boulder clay, and sometimes by beds of sand, on the removal of these accumulations, have displayed smoothed and striated surfaces, the direction of the striæ varying in different places; but, so far as I have observed, always taking a direction similar, or nearly so, to that of the valleys in which they are situated. Besides these striated surfaces there are other evidences of the local action of Glaciers. I have seen beneath the Boulder-clay, in the section exposed in the making of the Huyton and St. Helens Railway, and near Whiston, accumulations of unstratified materials, derived from the adjacent rocks, consisting of loose sand where there are Triassic rocks; of grey mud, containing fragments of coal, where there are Coal-measures. Combining these collections with the striated rock-surfaces, they can only be considered as moraine *débris*.

In Happy Valley, the tributary of the Mersey which forms the division between Oxton and Tranmere, and terminates at Tranmere Pool, the removal of the Boulder-clay has revealed several examples of these glaciated surfaces, whilst the excavation from time to time of those deposits which in the bottom of the valley overlie the sandstone, have afforded sections, limited in area, but not the less instructive in assisting to determine the circumstances under which the glaciation of the rocks and the accumulations of sand and gravel in the bottom of the valley have taken place; whilst the consideration of the whole will assist in forming an opinion respecting the manner in which the Boulder-clay has been deposited, not only here, but likewise in the surrounding districts.

There is now visible, close to the Presbyterian Mission House, grooves deeply cut in the Triassic sandstone, sufficiently large to receive a man's finger; and another striated surface is situated in the adjoining field at a very short distance from a pond, though superficial, these striæ are very distinct. A few years ago an example might be seen at the further end of the field, but, being in a soft sandstone, the grooves have now been entirely erased by weathering. In these instances the striæ have a direction of N. 40 W. There is another, now covered over, higher up the valley, in the unfinished street, nearly opposite a boss of current bedded sandstone, cut through in making the Happy Valley road, from which it is sixty yards distant; the direction of the striæ is due magnetic north. A small surface, about a yard in length and a foot and a half in breadth, is exposed close to the road, about seventy paces from Carlton Road, the striations being placed thickly together, and having a direction of N. 20° W. (See sketch Map.) *

Between Glover Street and Carlton Road the Triassic strata dip up the valley at an angle of 10°. As a consequence, at the basset edges the beds appear as if the rock has been broken off in the opposite direction in a steplike manner, as represented in the diagram Fig. 5; the hollows thus formed are filled with sand and gravel, the whole being covered with Boulder-clay.

In one of the sections (Fig. 4) the fracture appears to have progressed to the extent of cracking the upper portion of the bed only, slightly displacing the rock, and forming fissures in various directions, from half an inch to an inch and a half in width, which have been filled with sand and clay, having minute erratic pebbles intermingled.

On the bottom, and extending somewhat up the flanks of the valley, there are, underlying the Boulder-clay, beds of loose materials, sometimes of sand and fragments of sandstone derived from the immediate neighbourhood, not distributed by the action of water nor mixed with materials derived from distant sources. This I will designate *moraine*-formation; also similar sands which have been re-distributed, some of which contain an abundance of pebbles, sometimes fine, in other places larger, similar in kind to the erratics which occur in the Boulder-clay. These beds of drifted materials, as well as the underlying Triassic Sandstone, have at different times been excavated in various places, sometimes as areas for building, at others in order to make use of them for building materials. The most interesting sections are situated between Glover Street and Carlton Road. (A record of each exposure should be made at the time, lest it suffer damage from the weather, or be covered up in subsequent operations by the workmen.) At the corner of Carlton Road the sandstone is covered with an accumulation of yellow sand, so little altered in appearance from the underlying rock that, were it not for the occurrence of thin bands of brown sand and of patches of sand containing erratic pebbles, it might, without special attention, be easily mistaken for the soft Triassic Sandstone *in situ*. In some places a band of this pebbly sand separates this moraine-like accumulation from the sandstone; in others the moraine itself is divided by this washed sand, whilst in this locality a thin layer of it separates the moraine from the Boulder-clay. (Figs. 1 and 2.)

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* Mr. Bostock was the first who observed striated surfaces in Happy Valley.

Two or three years ago an excavation was made in irregularly stratified beds of gravel and sand containing small rolled fragments of shells, accumulated in a channel nine or ten feet wide, which had cut through a moraine accumulation and the Triassic Sandstone to a depth of eight or nine feet. The sides of the moraine and also of the sandstone were perpendicular, the latter even overhanging at one part. (Fig. 1.) There are other places where the sandstone has been hollowed out and worn as if by streams of water, the channels having been subsequently filled with gravel and sand (as in Fig. 2).

"Sub-glacial rivers are familiar in all alpine countries, and in Greenland pour out from beneath the Glacier, whether it lies at the *sea* or in a valley, in summer and winter."* It appears most in accordance with concurrent phenomena, to attribute the formation of these channels to the action of such streams issuing from beneath a Glacier extended some distance into the sea. The striæ left on the Triassic rocks and the moraine sand indicate that a Glacier existed immediately before the excavation; whilst the thin beds of pebbly sand interbedded with the moraine show that, at the time of their occurrence, the latter was beneath the water; so also do the perpendicular walls, especially of the loose sand, which, had it experienced a few days of subaërial exposure, would have been reduced to an acute angle, or washed away entirely.

Not a very long time could have elapsed—not long enough for tidal or other currents to remove the moraine accumulation—before the Sub-Glacier stream ceased to flow through this channel with sufficient force to counteract the action of the sea. The Glacier must have receded, possibly by its diminution; but, as the period of intense cold continued long afterward, it may quite as probably have been from persistent depression of the land, causing a greater depth of water, by which a Glacier of the same thickness would be floated and broken off higher up the valley. At all events, the force of the current issuing from beneath the ice was so lessened that it no longer kept for itself this passage, but the channel became filled up in the manner described.

On the bottom of the valley, between Carlton Road and Glover Street, and somewhat up its western flank, the Triassic Sandstone and the moraine accumulations, where they exist, are covered with beds, sometimes of sand only, sometimes of sand mixed with small fragments of rock foreign to the district, such as are so abundant in the Boulder-clay, but never, so far as I have observed, having any striæ upon them; there are also beds of gravel, chiefly consisting of these erratic pebbles of various sizes, occasionally containing large boulders of Granite, Trappean, and other rocks, as well as fragments of Triassic Sandstone, and sometimes blocks of the Boulder-clay itself. (Figs. 2–4.) The beds of sand are also sometimes interstratified with thin bands of this clay. In different beds there are also a considerable number of fragments of marine shells, so broken and rounded by attrition as not to admit of identification. The area in which the individual beds retain the same character is very limited; their materials have been repeatedly heaped together, portions have been again removed, to be afterwards overlaid by others in which the deposit differs somewhat in composition; these processes have been repeated again and again.

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* Dr. R. Brown, *Quart. Journ. Geol. Soc.*, vol. xxvi, p. 681.

Some years ago there were exposed at the lower part of the valley, near the Gas-works (*a* on Map), beds of sand and small erratic pebbles, containing an abundance of shells, mostly comminuted, but many were perfect, or nearly so; the species of these have been determined by Mr. Morton.* These shells could not have lived at the place where they were found, but must have drifted from a locality situated at a comparatively short distance, and where there must have been conditions suitable for their existence; but as yet I am not aware that any beds referable to the Glacial Period have been discovered, with similar shells in the place where they had existed.

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* "Proceedings of the Liverpool Geological Society," Session 1871-72, p. 92.—Excavations have very lately been made near the Gas-works, in thick beds of similar sand; but only fragments of shells were found, all very much comminuted.

There was at first considerable difficulty in making a reasonable explanation of the presence, in the Drift gravel and sand, of the blocks or pebbles of Boulder-clay (Figs. 2, 3); they are angular in form, and therefore had not been exposed to attrition, or rolled, in the same manner as are the balls of clay so commonly found upon our shore. In accounting for them, circumstances which are known to have been then existing must be taken into consideration: that a Glacier extended into the sea within a few score of yards of this place; that the bay was closely packed with innumerable ice-bergs and floes; that the Boulder-clay, with its countless ice-borne erratics, was after a short time deposited above the sand and gravels in which these blocks lie; and that the deposition of this clay must have been in progress at the same time near the mouth of the Mersey. Regard must also be paid to the recorded effects of Glaciers in the Arctic Regions which appear somewhat similar. Dr. Brown remarks that "if a berg grounds on a bank or shoal, or in any water not deep enough for its huge bulk to float in, it will often bring up from the bottom boulders, gravel, &c., deposited by former bergs," and "the clayey bottoms of shallow inlets will be grooved and torn up by grounding bergs."* I think it is more than probable that icebergs may have grounded upon some lately deposited bed of Boulder-clay, and again floating off, bore away portions of it, and drifting to this locality, on melting, dropped their load here. If this is the true explanation of the origin of these blocks, the production of the thin and localised bands of clay before alluded to may have arisen from the same cause; some of these blocks after they have fallen down may have become dissolved, and thus spread over a more extended surface.

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* *Quart. Journ. Geol. Soc.*, vol. xxvi, pp. 687 and 690.

Lower down the valley, from about the Mission House to the Gas-works, beds of sand which have been exposed beneath the Boulder-clay are remarkably free from erratics, excepting those of a minute size, which are there in abundance. The same may be considered to be the general condition of those cut through near Grange Lane in making the new railway tunnel (*b* on map), though some larger ones were thrown out amongst the materials removed. So great a difference between these beds and those situated higher up the valley, leads to the inference that each had been formed under somewhat different conditions; there must, in the former instance, have been some impediment to Glaciers, laden with erratics, floating over the immediate locality, otherwise there would not be this absence of large pebbles; the smaller ones are such as might have been brought from a short distance by currents, and thus became mingled with sand derived from the disintegration of the Trias.

Mr. Morton has described these "Lower Drift Sands and Gravels" chiefly as they occur beneath the Boulder-clay in the cliffs forming the boundaries of the Mersey:—"The beds of gravel are of limited extent—mere nests or patches distributed through the sandy strata—frequently containing fragments of shells, and sometimes perfect specimens;" and he considers that "the deposit has probably originated from the disintegration of the Triassic rocks, immediately before the deposition of the Boulder-clay."* The late Mr. John Cunningham C.E., F.G.S., found beds of loose sands and gravels, with fragments of shells, in sinking for water close to Wallasey Pool; these loose strata proved so great an impediment that he was obliged to sink the well in another place. Mr. Bostock found the same in boring in the valley of the Fender on the Upton Road to determine the character of the underlying rocks. He has also supplied other localities, where the same have been met with in borings and well-sinkings, which Mr. T. M. Reade, F.G.S., has recorded in our Proceedings, with many that have occurred to himself and friends.[†] These gravels and sands appear to occur either on the bottom of valleys which had lately been filled with Glaciers or a little way up their flanks.

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* "Geology of the Country around Liverpool," by G. H. Morton, F.G.S., p. 42.

My observations lead me to the conclusion that 225 feet, or it may be something less, was the greatest thickness of the Mersey Glacier in mid-channel. In excavating for the foundations of a building connected with the Birkenhead School, at the height of 200 feet above the rocky bed of the Mersey, there was exposed, in an accumulation of moraine breccia, consisting of angular fragments of sandstone and loose sand, a hollow place or channel about a yard and a half wide and a foot and a half thick, filled with a whitish clay, such as is commonly found as balls or pebbles in the Keuper Sandstone or as beds interstratified with the sandstone; both the *débris* and the clay are covered with Boulder-clay. This moraine covers a considerable surface, both below and above the school-house, and has been derived from the sandstone in the immediate vicinity. It does not appear possible that the Glacier which originated it could have formed an integral part of that which filled the valley of the Mersey, and, extending over the present site of Birkenhead, passed through the gorge between Bidston Hill and Wallasey.* Had such been the case, everything must have been swept onward in its passage towards the sea. It is more probable that this *débris* may be ascribed to the effects of an accumulation of snow on the land between it and the water-parting, causing the degradation of the rocks, and by its movement carrying down the disintegrated materials to near the sea-level at that time. The limited deposit of clay would have originated from percolation of water through this moraine, washing out from the disintegrated sandstone of the Keuper the clay it contains in such abundance; and this settled in this hollow or pool, separated in some way from the waters of the ocean. If such was the cause of its formation, or if the Glacier of the Mersey, by floating, was separated from that upon the summit of this ridge, the greatest thickness of the the Glacier could by no possibility be greater than the amount specified, being the height of the locality above the rocky bed of the Estuary, with the addition of one-eighth for flotation. It is desirable for the confirmation or refutation of this suggestion that advantage be taken of any opportunity afforded by excavations on either side of the Mersey, at heights from 120 to 160 feet above the sea level.

[†] "The Buried Valley of the Mersey."—Proceedings of the Liverpool Geological Society; Session 1872-73, p. 42.

The Boulder-clay containing abundance of ice-marked pebbles derived from distant sources† is so well known that there is no necessity to direct attention to its characteristics further than to notice the occasional occurrence in it of flints. They have been observed but seldom by Mr. C. E. de Rance, F.G.S., of H.M. Geological Survey; more frequently by Mr. D. Mackintosh, F.G.S., and by others. Though not common, these flints may generally be found after a prolonged search, but sometimes several are situated close together. I found five or six thus placed off the Red Noses, New Brighton, and about the same number within an area of a square yard on a bank by the roadside at Neston. Mr. A. Strahan, F.G.S., of H.M. Geological Survey, told me that he also has met with several near together.

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* "Glacial Phenomena of Western Lancashire and Cheshire," by C. E. De Rance, F.G.S.—*Quart. Journ. Geol. Soc.*, vol. xxvi., p. 652.

† Since the reading of this paper, I have found a very large number of erratic boulders, some of which, sculptured by the action of the weather, bear no evidences of glaciation or rolling; the others, with a greater or less amount of ice-polishing and scratching, are also distinctly weathered.

I have met with flints in almost every brickfield in the Birkenhead district, but some from Happy Valley are so remarkable as to deserve particular notice. The largest specimen has a portion split off at one end, and appears much weathered; projections on its rounded end are abraded, not smoothed as flints usually are which have been exposed to grinding action on the shore, but as if little fragments had been chipped out by forcible pressure against some hard substance. This erosion does not affect even superficial depressions on the surface. A fragment of another has been exposed to the same chipping, and has also several small patches rubbed smooth and polished; one of these places is also striated. This and another of about the same size have been so altered by weathering that they are white throughout their whole substance. Another has a fragment of white limestone attached. This has a granular appearance; but, though thus altered, its hardness is such that it can only be referred to the Chalk or White Limestone of Antrim. I have also obtained a piece of similar limestone granular upon one side, whilst the other is smoothly polished and striated. The flints, weathered but not waterworn, coincide with those so abundant on the eroded surface of the Chalk of the North of Ireland, where they are overlaid by Basalt.*

Marine shells, all of littoral species, are found, but not frequently, in the Boulder-clay. Excepting *Turritella communis* and a solitary specimen of *Litorina litorea,* they are very seldom in a perfect state, being more or less broken, generally into small fragments. Embedded in a soft matrix of clay, their fractured state indicates that they have not existed where found, but have probably been conveyed and deposited in the same manner as the erratic boulders.

The smoothed surfaces of the rock, striated here and elsewhere in the general direction of the valleys, and in a similar manner to what occurs in countries where Glaciers now exist, indicate a period when here also the valleys were filled with Glaciers and perennial snow covered the district. The loose unstratified sand which I have called 'moraine,' containing no materials foreign to the neighbouring rocks, is found in numerous places elsewhere. Combining these accumulations with the existence of Glacier markings on the rock surfaces, they can only be considered as having been derived from the grinding of Glaciers upon the rocks, and were carried forward in their progress until this *débris* has been left behind at the termini. As they have been formed at the foot of the Glacier, it follows that the Glacier must have moved *down* the valleys; and, with the occasional occurrence of interbedded bands of sand containing fragments of marine shells in connection with them, it follows that the termination of the Glacier was in the sea. These conclusions respecting the local origin of the Glacier have been confirmed by other observations; as the tributary Glacier from Tranmere meeting that from Happy Valley at an acute angle; the Triassic beds fractured off where the rock projects at Glover Street (Fig. 5); and the channels, especially the one at Carlton Road (Fig. 1), formed immediately after the recession of the Glacier.

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* Mr. Isaac Roberts, F.G.S., possesses a specimen of flint exactly similar to those which, at Belfast, are situated in the hollows formed on the eroded surface of the Chalk, and lying immediately under, have been altered by exposure to the action of the Basalt.

The land during the Glacial Period must have been covered with perennial snow, and many a Glacier, filling the valleys of Cumberland, Wales, and Ireland, extended into the sea, and gave origin to bergs, numbers of which, under the influence of prevailing winds, drifted into the Bay of Liverpool and Estuary of the Mersey, and, melting, dropped their load of ice-marked pebbles; but every phenomenon is in direct antagonism to the hypothesis of a monstrous Glacier filling the Irish sea, or of one extending from the mountains of Cumberland, across the Bay of Liverpool, and over the Island of Anglesey. With such supposed barriers, no sea could have existed between them and the mainland; none of those pebbles with which the Boulder-clay is studded could have passed over and reached the situations where they are embedded in it; least of all could those ancient Irish immigrants, the flints and pieces of Chalk from the Antrim district, have crossed such an obstruction.

That there were no powerful currents is shewn by some of those accumulations in the sea, which I have termed moraine sand, not being re distributed; by the removal of the sandy and gravelly beds being partial only; and their re-deposit, though frequently repeated, being very localised, as is shewn by the different sections, especially in the one represented in Fig. 3. Little more could have been effected by the tide than was due to its rise and fall. The bottom of this valley appears to have been somewhat deep in the water, but there must also have been an obstruction to the water rushing up and down it, constituting the ebb and flow of the tide. The presence of a Glacier within a short distance of these Drift sands and gravels, as proved by other evidence, would act as such a barrier to the ingress of the sea. So that, on that account, and the deep water occupying the Bay and Estuary, the tidal currents must have been exeedingly slight, and probably much of the erosion of these beds, and their re-distribution was due to Sub-glacier streams. The absence of stratification in the Boulder-clay is most remarkable, whether it has been deposited in what must be presumed to have been deep water, as in the bottom of the valleys, or where it has been shallow, as on their flanks and ridges. Had currents existed of even moderate force during the time it was being deposited, some re-arrangement of the sands and pebbles would have taken place, giving to it a bedded appearance. Reasons have been shewn why the rise and fall of the tide should not have affected these deposits; but there would have been some evidence of stratification, at least in what is now higher ground, had there been such wave action as occurs now. The Boulder-clay contains in the arrangement, or, rather, want of arrangement of its innumerable ice-marked pebbles, the clearest evidence that never in these waters did wind-waves then exist. The floating ice and bergs which conveyed these pebbles must have covered the bay so entirely that, protected by an immense accumulation of pack-ice, the winds, however tempestuous, had no such effect in disturbing the water as to distribute the constituents of the Boulder-clay in a stratified manner.

In attributing the great difference of climate prior to, during, and after what is called the "Glacial Period" to astronomical causes, whether due to increase of the obliquity of the ecliptic or of the eccentricity of the earth's orbit, or to other influences, it has usually been considered that the effects produced were dependent upon a general increase in the intensity of cold only; that the more the temperature was diminished the greater would be the amount of snow precipitated, and, in the Northern Hemisphere, the farther south Glaciers extended the greater would be the snow-fall in the north.

Before intense cold could precipitate water contained in the atmosphere in the form of snow, heat at or near the Equator was required to saturate the air with this moisture. In reference to this subject, Professor Tyndall remarks:—"In this process of distillation, *heat* plays quite as necessary a part as *cold*. Before Bishop Heber could speak of 'Greenland's icy mountains,' the Equatorial ocean had to be warmed by the sun."*

In passing over land surfaces, even in temperate climes, the atmosphere parts with much of its moisture. In our own island the rainfall on the east coast is only about a third of what it is upon the west, where the winds which have traversed the Atlantic first impinge upon the land.

Though in Siberia the intense cold of winter has for ages so far exceeded the warmth of summer that the ground is frozen to the depth of at least six hundred feet, yet sufficient moisture has not been retained in the air which traverses the continents of Europe or Asia to produce perennial snow; for in passing, during August, 1875, up the River Jenisei from its mouth, Professor Nordenskjold, of Sweden, "saw snow only at one place, a deep valley cleft of some fathoms extent." But the severe cold and long absence of light of the Arctic winter had not prevented the warmth of the summer's sun producing within the Arctic Circle "a vegetation remarkable for a luxuriance, to which he had seldom before seen anything corresponding. In a territory, part of which lies north of the Arctic Circle, are found the most extensive and finest forests of the Globe." * He refers to a fact which he considered improbable beforehand, that "the northern limit of many plants in Siberia is situated farther towards the north than in Sweden. It appears that the severe winter of Siberia has by no means any specially injurious influence on the vegetation of the summer." †

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* "Forms of Water," p. 21.

Compared with Greenland, no great accumulations of snow takes place in the Parry Islands, "no Glaciers of any size exist, westward of the 85th meridian of west longitude in Lancaster Sound, and no true icebergs are met with in the Great Arctic American Archipelago. Here and there, in dark and sunless ravines of North Devon and Melville Island, a diminutive Glacier may be found, but it never reaches the sea so as to form icebergs." ‡

Reasoning from Professor Nordenskjold's report, it appears that, if there is the warmth of summer—in other words, if there is no greater amount of snow on the ground than can be readily melted by the sun's rays —no intensity of cold or absence of light in winter has the effect of preventing, even within the Arctic Circle, the growth of luxuriant vegetation. It may have been quite possible that trees and plants, as abundant as those found at Disco, Banks Land, Discovery Bay, Spitzbergen,

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* *Nature*, vol. xiii., p. 97. † Page 275.

‡ "Mc Clure's Discovery of the North-west Passage," edited by Captain Sherrard Osborn, C.B., p. 149.

&c., may have flourished in these latitudes during a Glacial Period affecting more southern localities; for, after passing over land covered with snow and seas filled with bergs and floes, there would remain in the air no more moisture than would supply snow readily melted when summer commenced.

On the discovery of these plant remains in these high northern latitudes, it was generally—I believe universally—considered that it would be quite impossible at the present time that vegetation, such as can be called luxuriant, could exist within the Arctic Circle. Dr. R. Brown, the chief collector of them in Greenland, says, "the very large number of species obtained from a very small space betokens a flora more tropical than temperate, for he is not aware that any similar area in Italy (with the temperature of which Dr. Heer compares the climate of Greenland at the time of their growth) produces a similar number of species. Yet the plants found are not those of the tropics, but of temperate regions." * The information respecting the River Jenisei supplied by Professor Nordenksjold may render necessary the re-consideration of the climatic conditions under which these fossil Arctic plants flourished. But if the species are such that they could not have existed with an intense winter followed by a warm summer, such as occurs in Northern Siberia, before attributing this difference in climate to astronomical causes, it will be well to determine whether any physical change has taken place or might reasonably be supposed to have occurred which, altering the relative positions of land and water might change the direction or force of the currents of the ocean, and induce in

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* "Geological Notes on the Noursoak Peninsula, Disco Island, &c." Transactions of the Geological Society of Glasgow, vol. v, part 1.

these regions a climate comparable with that of the temperate zone. The depression of Florida below the sea level (a circumstance which occurred in the Tertiary epoch) would greatly increase the warmth of the North Atlantic Ocean. Not only would the Equatorial waters escape from the Gulf of Mexico three hundred miles further north, but they would do so in much greater volume.

In 1851 Mr. William Hopkins, F.R.S.,* then President of the Geological Society, considered the effects which various *possible* changes in the configuration of the land, during recent geological times, would have in causing alterations in temperature. Amongst others he took into consideration the hypothesis of depression of the valley of the Mississippi so as to permit the Equatorial waters to pass in that direction into the Arctic Ocean. He concluded that the Gulf Stream would lose all sensible influence on the coasts of Western Europe, but would necessarily increase the temperature along its altered course, and especially in the cold regions of North-western America, towards the present shores of the Arctic Sea. Evidence is yet wanting of this supposed communication between the Mexican Gulf and the Arctic Ocean. The results of the examination of the Rocky Mountain district by the United States Survey indicate a period, referred to the Tertiary, when the relative conditions of land and water must have most materially modified the climate of the whole of the North American Continent. The base of the "Great Lignite" group of strata (Lower Tertiary) proves that "extensive tracts of country in the regions of the Rocky Mountains, and east of them in Nebraska and other north-western territories, were occupied by bays, inlets, estuaries, &c., of brackish water. The shores of these ancient estuaries, &c., supported dense forests of large trees, and a growth of other vegetation far exceeding in luxuriance anything now met with in these latitudes. The presence of true fan palms of large size, the remains of crocodiles, as well as the affinities of the mollusca found in these beds to southern forms, all point to the existence of a tropical rather than a temperate climate during their deposition."*

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* *Quarterly Journal of the Geological Society*, vol. viii.

The Equatorial waters, constantly propelled by the influence of the Trade Winds through such an extensive land-locked bay, inducing upon its shores a tropical vegetation, would by the warmth infused into the air so modify the climate farther north that the winter, rainy, cloudy, and foggy, would probably in no part of North America have had a temperature differing much from that of Britain at the present time.

The general idea that in high northern latitudes the country must be a desert waste, either covered by ice or snow, or by an exceedingly scanty moss vegetation, being so contrary to the startling fact, as described by Professor Nordenskjold, the re-consideration of the fossil flora of the Polar Regions may become a necessity; whether it may so far agree with that of the forests of Western Siberia that the plants of which it consists may have lived if placed under similar circumstances, and whether the geological position of all or any of these plant-beds would coincide with such a supposition as co-ordinates them with that of the Glacial Period farther south. The accounts of the fossil and sub-fossil plants of the Parry Islands may probably favour the idea of a

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* "United States Geological and Geographical Survey of Colorado, &c.," 1874, pp. 22, 23.

Siberian climate, whilst those of Disco, &c., may be incompatible.

The subsidence which, allowing the influx of Equatorial waters, produced a tropical climate in the central parts of North America, if it progressed farther south, and caused submergence to any considerable depth of the low ridge of land which forms the Isthmus of Panama, would permit the Equatorial waters to be propelled by the Trade Winds directly into the Pacific Ocean; and thus, in accordance with the extent of the immersion, the climate of the Northern Hemisphere would be entirely altered. Probably the accession of the Equatorial water of the Atlantic to that of the Pacific would so much increase the moisture of the atmosphere that, amongst other changes, the Himalayas would be covered with a greater fall of snow, and its Glaciers extend to a much lower level, especially on their southern aspect. The warm Equatorial waters would cease to circulate in the bay which once stretched into the interior of the North American Continent. The power which causes the Gulf Stream being diverted, this great ocean current would no longer exist; and that immense portion of the Equatorial water for which there is not sufficient area in the Straits of Florida to form part of its volume, and as an overflow mixes with the North Atlantic, would also be diverted in the same way. A diminution of temperature would follow sufficient to change the winter rainfall of Britain and Western Europe into a fall of snow; at the same time sufficient warmth would remain in the ocean to generate the vapour from which the snow would be derived, not in quantities such as many imagine occurred during the Glacial Period, but plenty to fill the valleys entirely with their respective Glaciers. This I have illustrated in the case of a minor valley, tributary to the Mersey, not because I do not think that the principle is of general application, but because I have there had special opportunity of examining the phenomena which have resulted from its action.

The observations on Central America have been too few to determine, from geological evidence, the former existence of such a depression as I have supposed, yet there is good ground for supposing that such has taken place.* All around the Bay of Mexico and on the western coast of Central America there has been a former subsidence of the land to a considerable extent below its present level. Many Mollusks† and Echinoderms‡ are found in the two oceans which are either identical or very similar in species. The altered conditions in the Pacific, upon a re-elevation of the land, must have been the destruction of a very large number of species; but the number in which this similarity exists is sufficient to lead the late Mr. P. P. Carpenter, Mr. Alexander Agassiz,§ and Professor Wyville Thomson to consider that they may be indicative of a former intercommunication between the two seas.

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* In reference to recent investigations of the fauna of Lake Nicaragua, by Drs. Gill and Bransford, it has been considered that "the element of especial interest is the association of characteristically marine forms, such as a species of Megalops, a shark and a saw-fish, with fresh-water types. The most probable cause of such a combination is the detention and survival of salt-water fishes in inlets of the sea that have become isolated and gradually transformed into fresh-water lakes." *Nature*, Oct. 11th, 1877; page 505.

† "The Mollusca of the West Coast of North America," by Philip P. Carpenter.—Report of the British Association, 1856, p. 363.

‡ "The Depths of the Sea," by Professor C. Wyville Thomson, F.R., &c., p. 13.

§ Quoted in "Depths of the Sea," p. 14.

Birkenhead, 1877.